Predicting future change in water flows and quality in urbanising catchments

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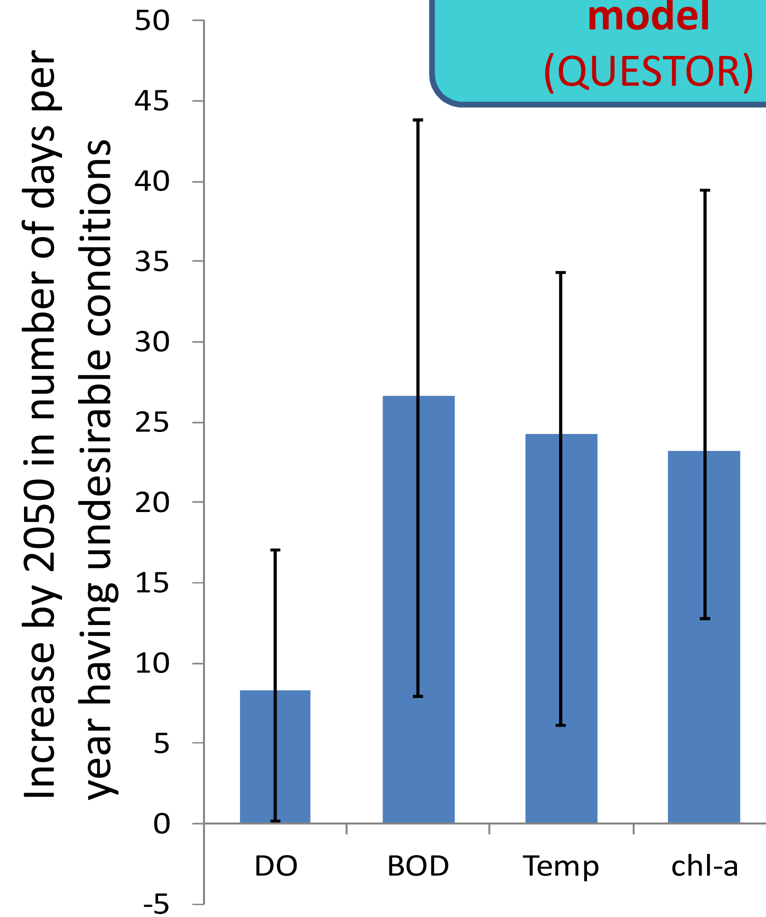
Water quality by 2050 in the R. Thames

1. Climate model
(Had-RM3)

2. Rainfall-runoff model
(Future Flows)

3. Water quality model
(QUESTOR)



- QUESTOR river water quality model (daily timestep. Parameters include chlorophyll (phytoplankton) and dissolved oxygen
- Due to sunnier/warmer/drier conditions, eutrophication is likely to become more prevalent and severe in the Thames…. But this assumes no population change

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A NERC Changing Water Cycle project…

- **POLLCURB investigates how water pollution relates to change in urban areas, in particular brought about by population growth (16% to 2035). Focus on Thames basin.**

- Measuring land cover, river flow and quality in urbanising case studies (Bracknell/Swindon), and thereby by developing better models…

- Leads to…. a better understanding of how urban areas affect our water resources so we can better plan future urban developments to lessen any unwanted impacts

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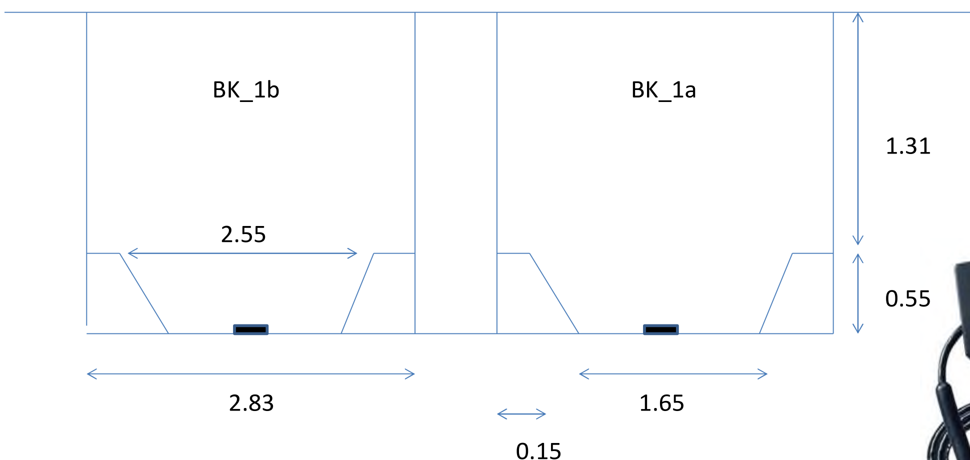
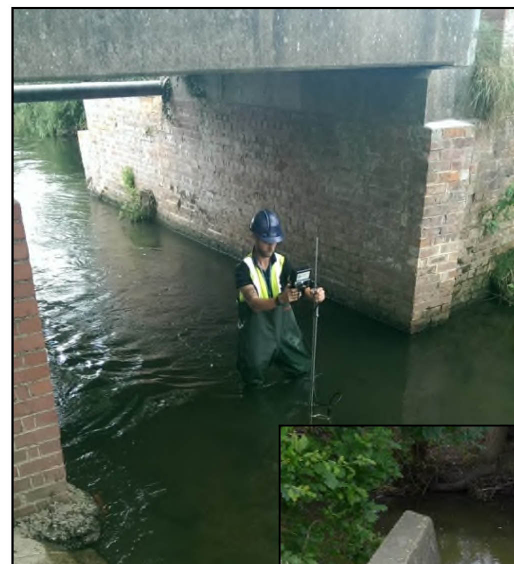
Stream water monitoring

- EA long-term records
- 2 years sub-daily monitoring: rainfall, flow, water quality (pH, turbidity, temperature, conductivity, ammonium, DO).
- Site-specific spot gauging to confirm velocity measurements and calibrate rating curves (depth-flow)
- Suspended sediment analysis corroborates optical turbidity



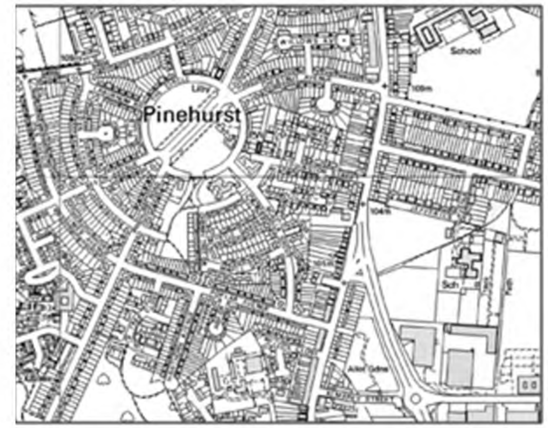


Land-cover change

Satellite imagery
(5 images since 1975)

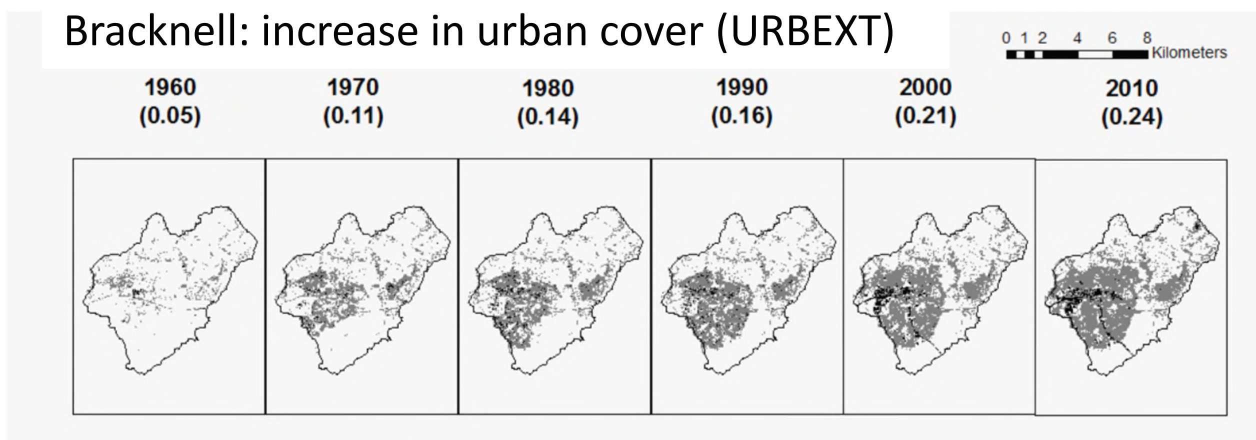
Aerial photography

Topographic mapping (OS)



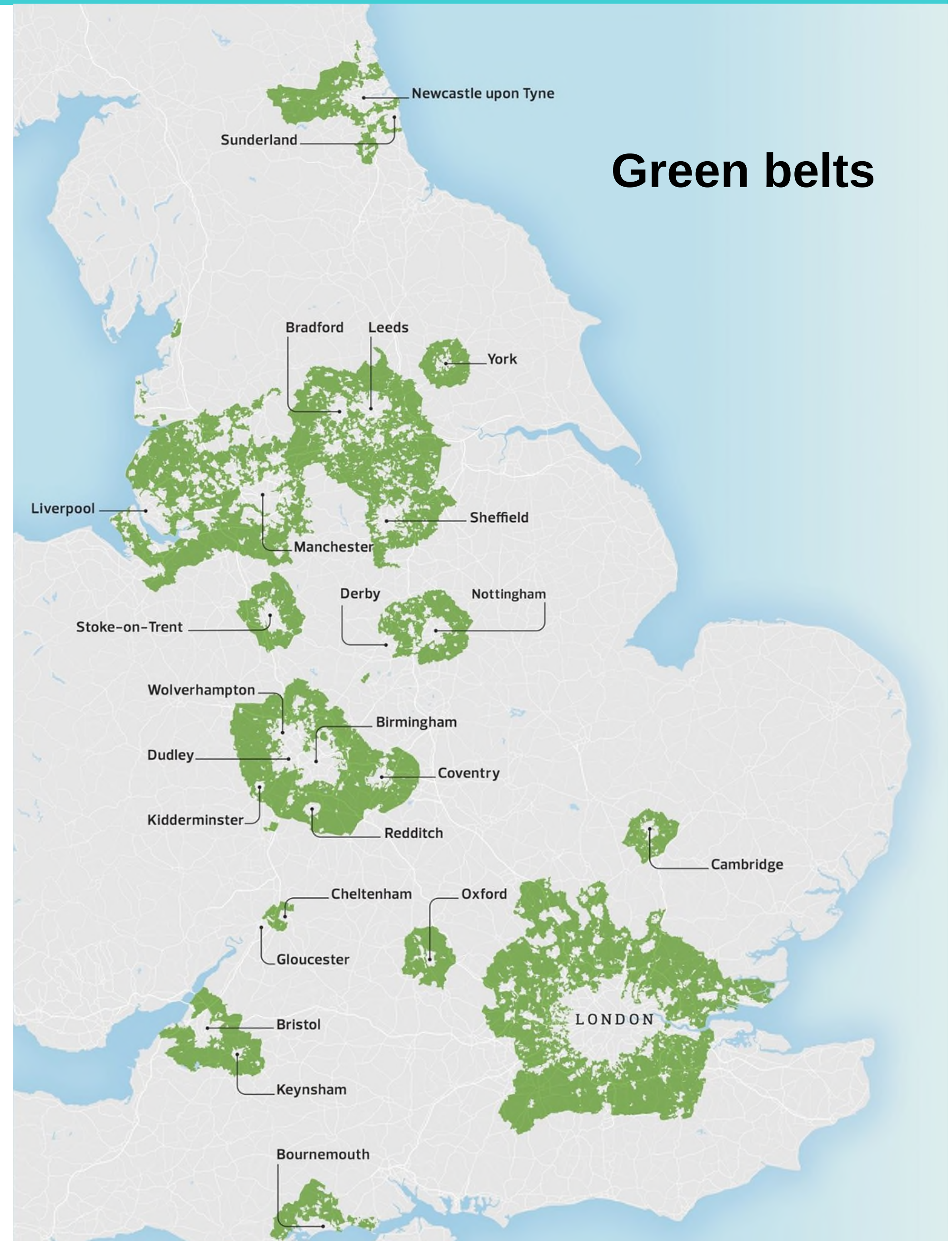
Derivation of indices of the percentage of impervious surface cover.

The sources of information are compared where possible, making for robust estimates



Urban growth modelling: data requirements

1. 1984-2015 POLLCURB land cover time-series
2. UK Census data on population and households at fine geographic resolution (1981-2011)
3. Risk of Flooding from Rivers and Sea (2014)
4. UK Green belt areas (2014)
5. ONS Population projections by Local Authority (2015)



Graphic by Pete Guest for the Observer New Review

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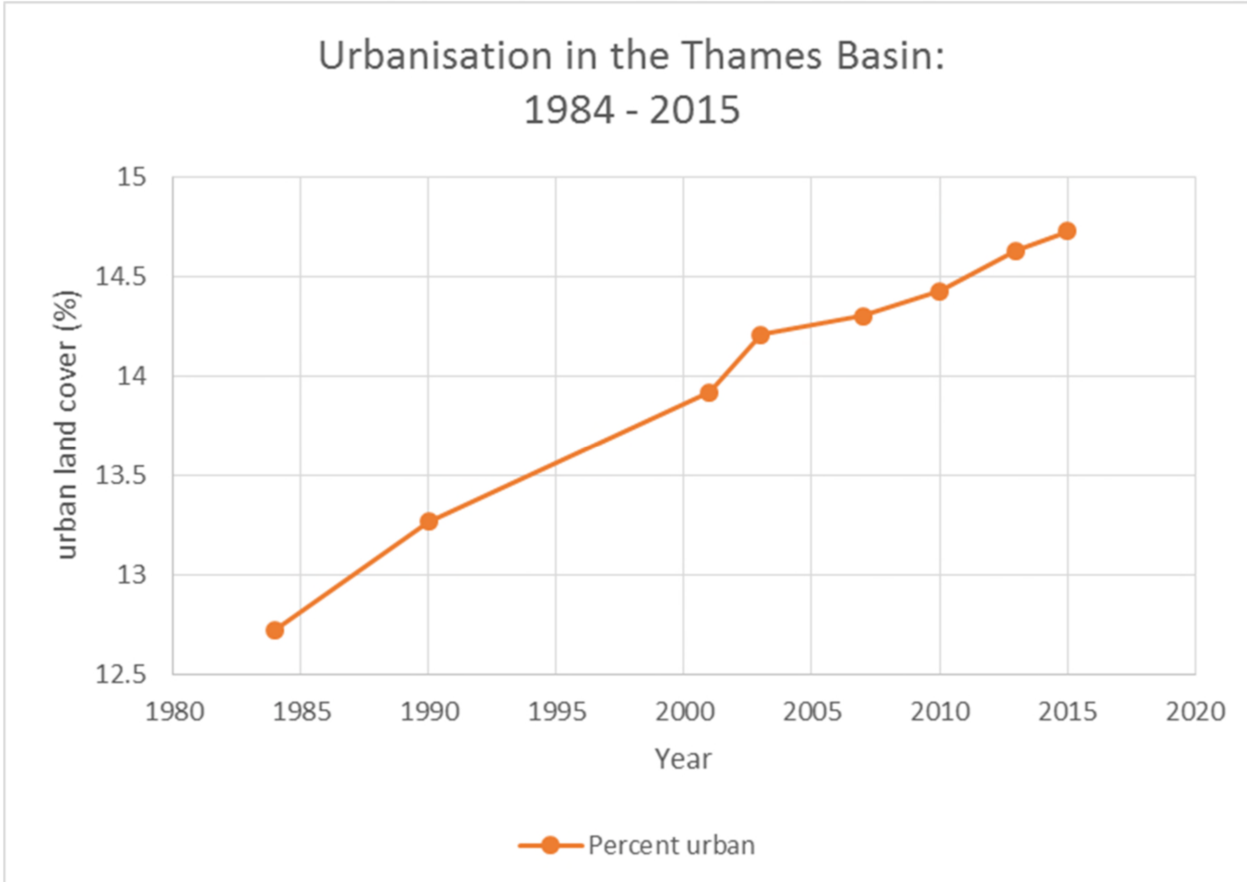
Land-cover: 5-class, 200m raster, 8 snapshots (1984-2015)



- Population density within ‘Urban’ and ‘Suburban’ categories appears stable over time
- Green belt status dominant in directing population growth to expansion of mid-sized towns and densification in towns encapsulated by green belt

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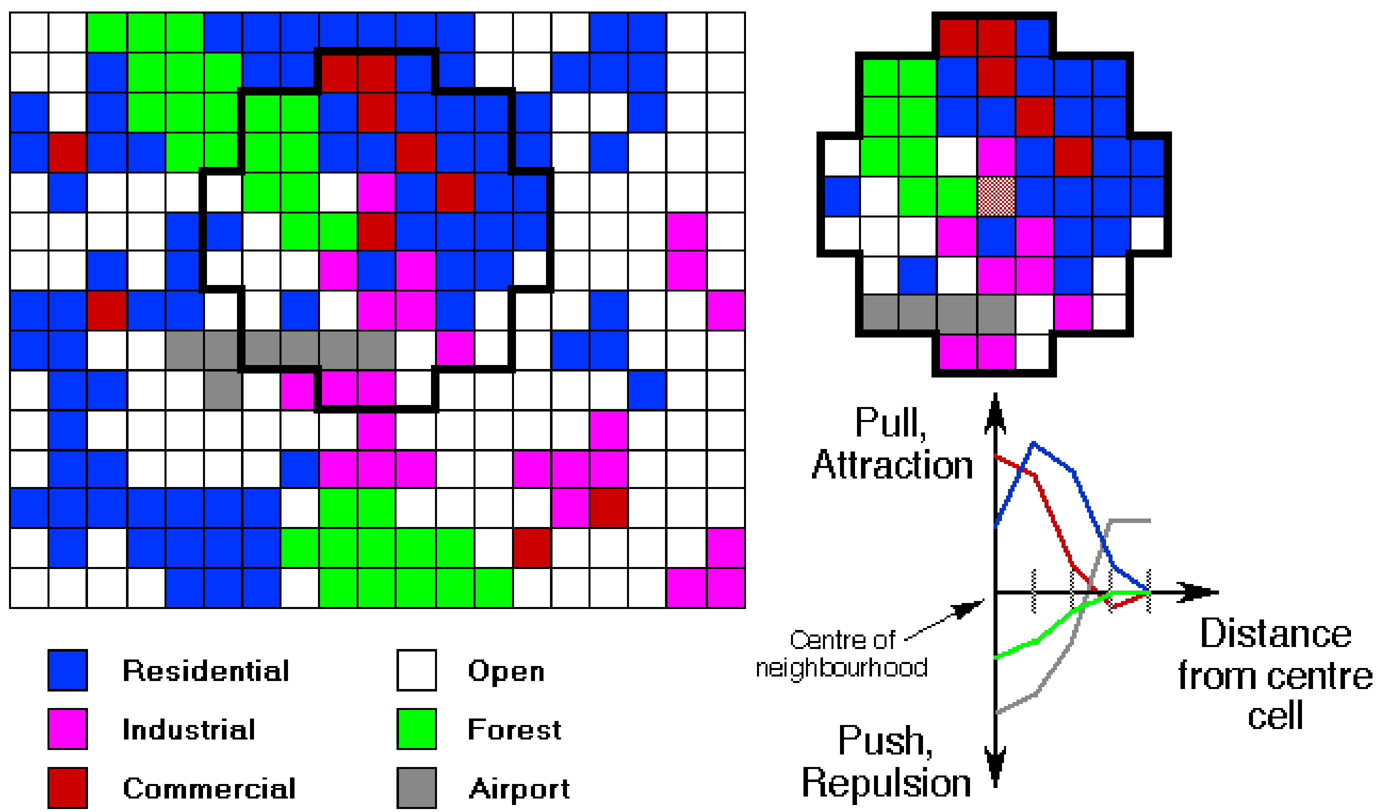
Constraint Cellular Automata land use model

- Calibrated to historic land cover
- Derived URBEXT projections for catchments (2015-2036) under 3 scenarios of urban growth.

1. Current rate of densification: continued green belt observance
2. Low densification: relaxed green belt observance
3. Moderate densification: relaxed green belt observance where observance where indicated in Local Authorities spatial planning documents



© RIKS, Guy Engelen

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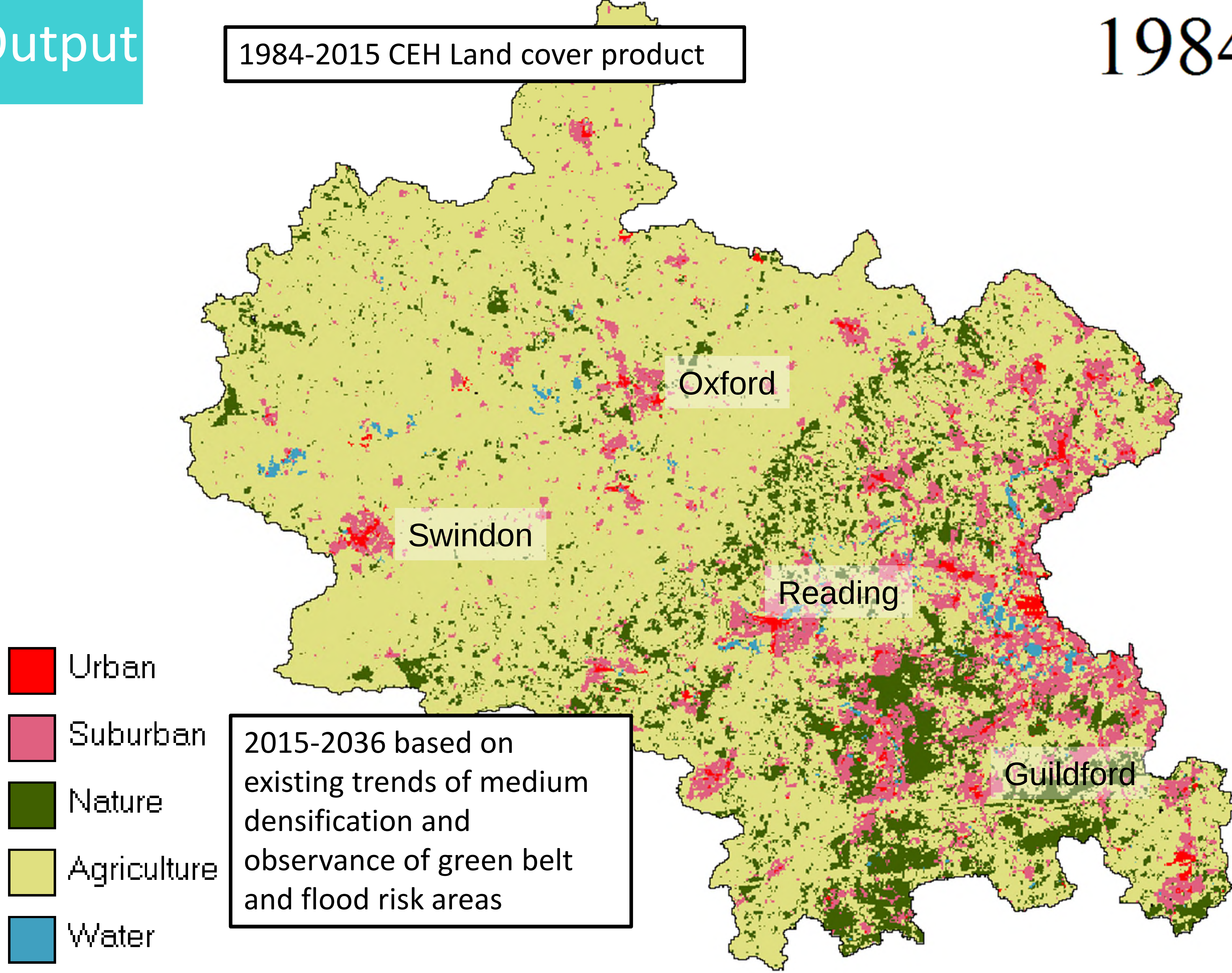
CCA Model: White, Engelen & Uljee 1997

Output

1984-2015 CEH Land cover product

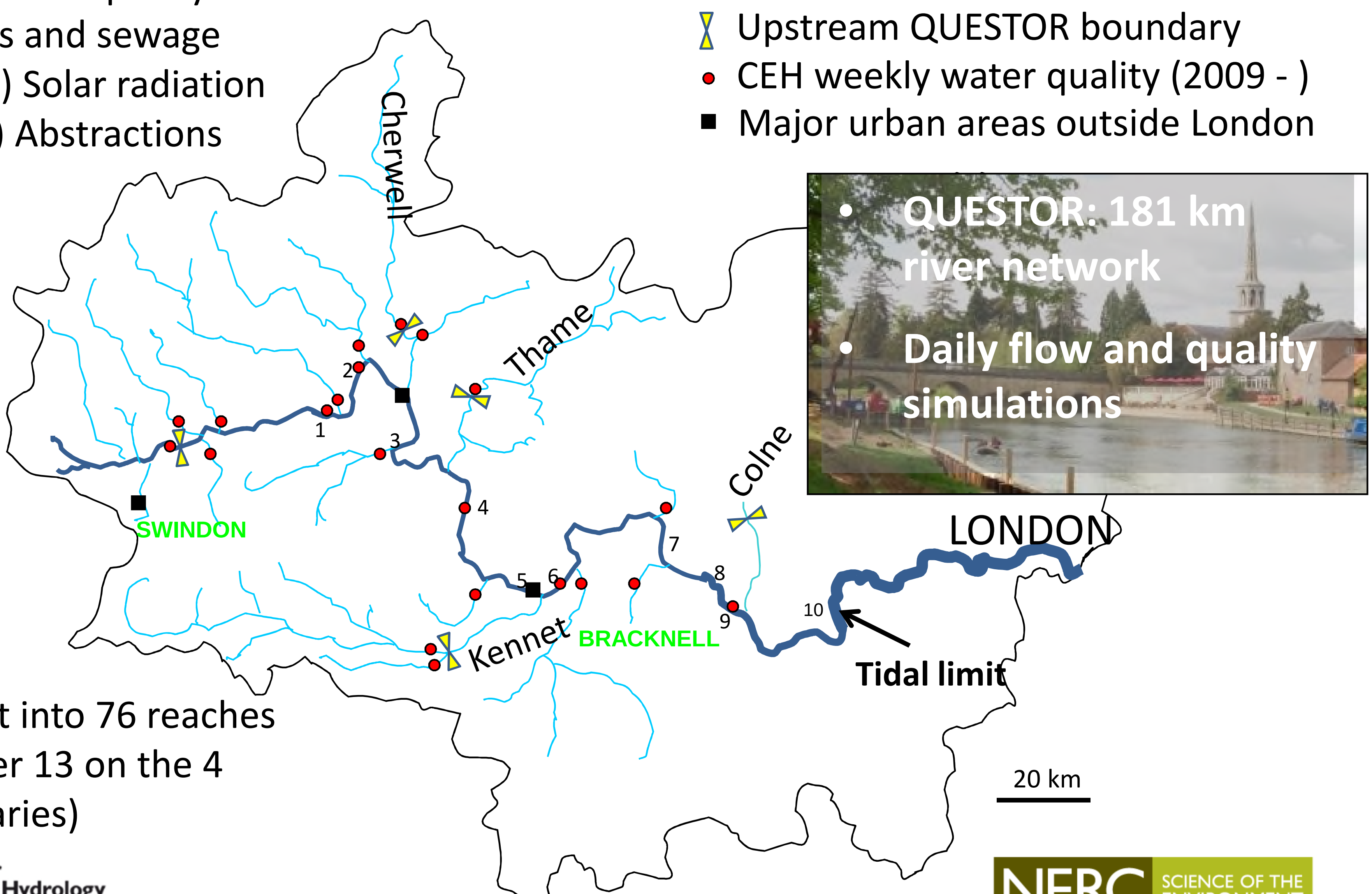
1984



2015-2036 based on existing trends of medium densification and observance of green belt and flood risk areas

An integrated Thames model of urbanisation impacts

Model drivers: (1) Flow, temperature and quality data in tributaries and sewage effluents, (2) Solar radiation (3) Weirs (4) Abstractions



Thames split into 76 reaches (Plus another 13 on the 4 main tributaries)

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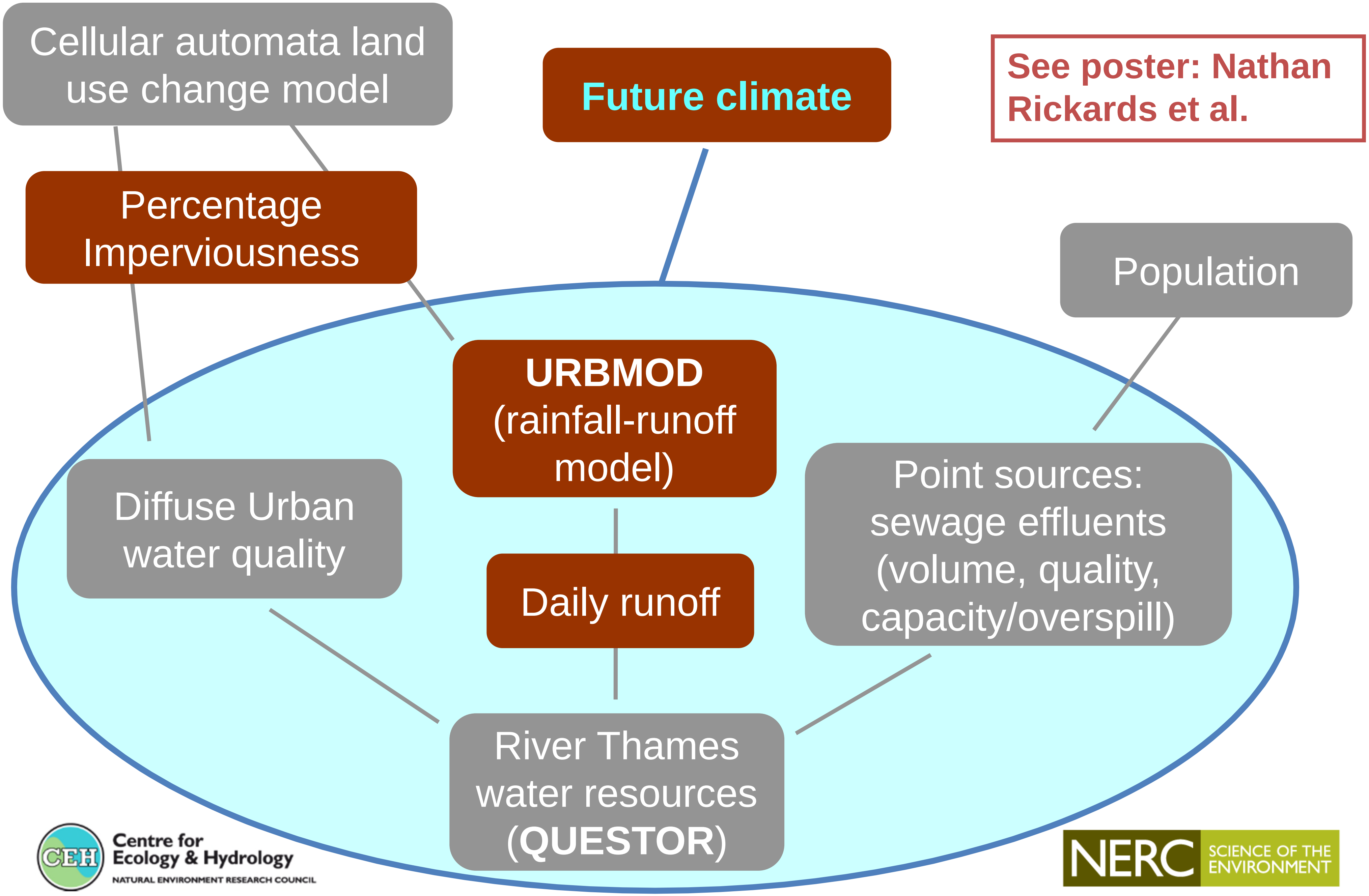
Integrated modelling concepts/chain



Urban pollution: complex sources/system

Sources
In-situ sediment
Runoff: roads and paved areas
Trading estates (poor waste control/storage)
Misconnections in separate storm/foul sewer systems
Sewage and household waste
Contaminated land runoff

Mechanisms	Timing
Overflows: • Combined sewers • Storm tanks at sewage treatment works deliver untreated sewage	During/following heavy rainfall
First flushes of accumulated pollutants via surface sewers	Rainfall following dry spells
Treated effluents at sewage treatment works	Continuous: especially important at low flow
Leaky infrastructure	Continuous

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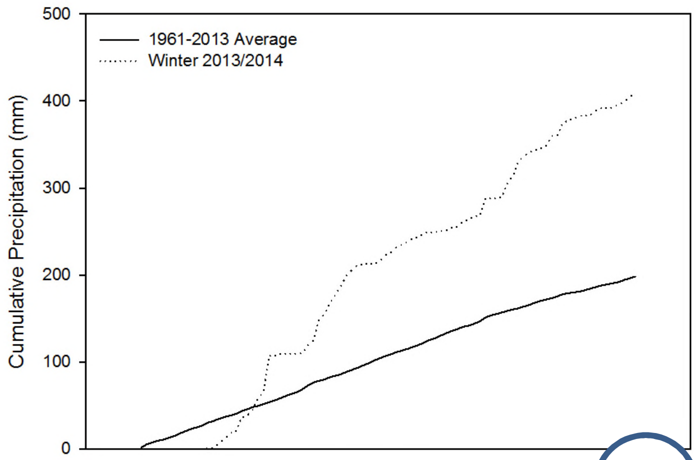
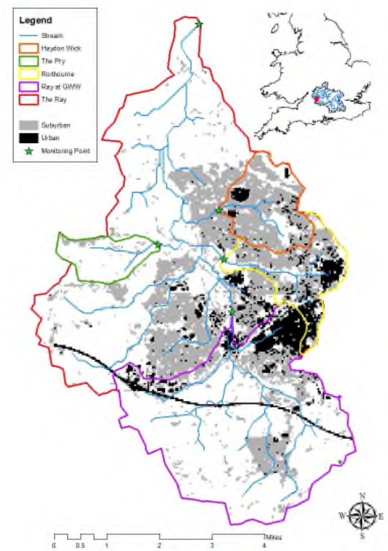
Additional impacts: of building works

- Upgrade of Swindon sewer network involves a whole new sewer system being installed – with significant site works and re-routing of drainage
- Continuous monitoring showed evidence of raised suspended solids in River Ray

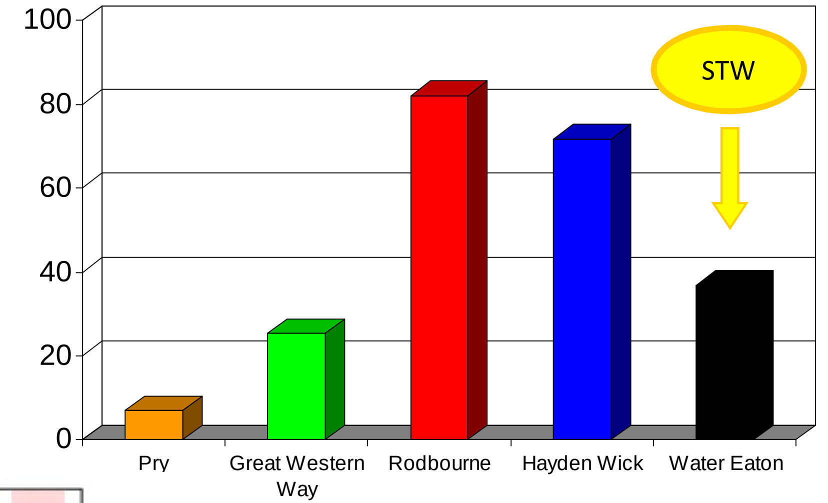
Winter 2013-14 storms in Swindon

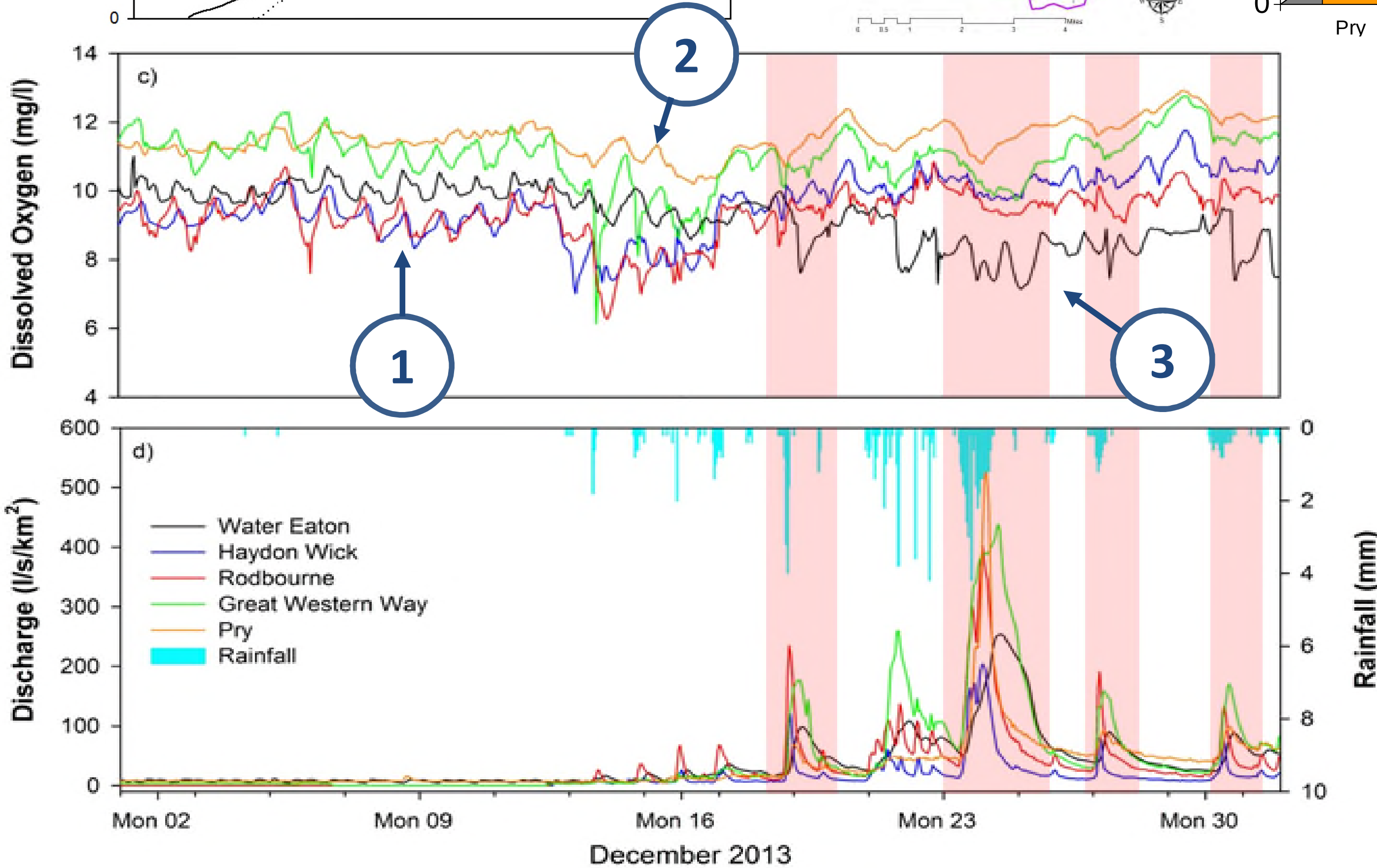
Ray at Water Eaton (84 km^2)





Sub-catchments (% urban cover)





1. Rural-urban gradient at low flow
2. Transient low DO in sub-catchments a response to pollutant first flushes
3. Chronic low DO only seen at Water Eaton, not elsewhere. Overflow at sewage works (STW)?

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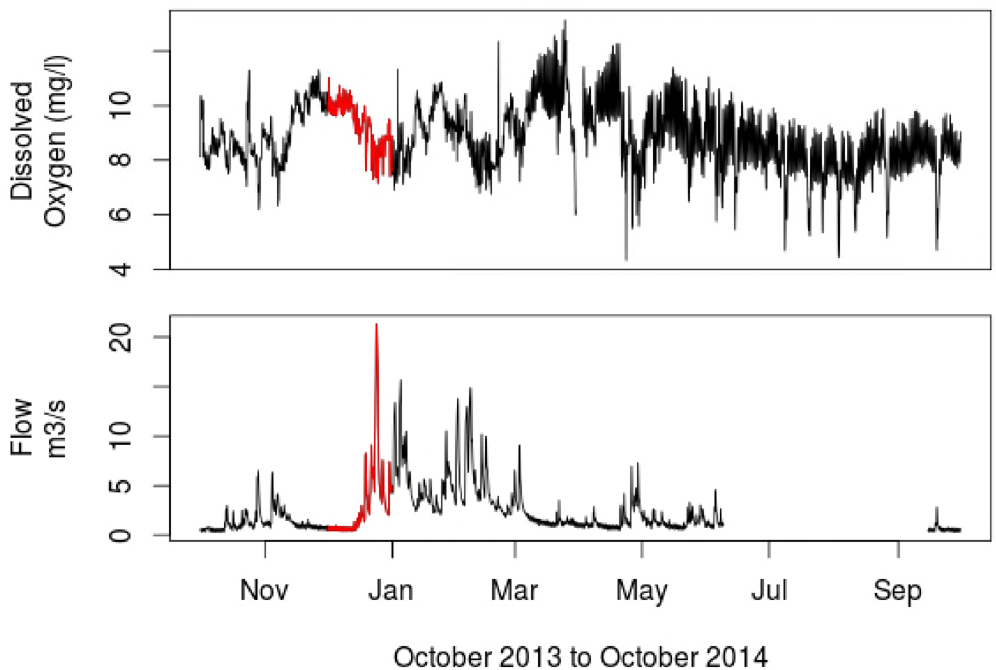
Winter 2013-14 very extreme

- Ammonium concentrations violated WFD good status criterion at sites impacted by STW, but not elsewhere: the Hayden Wick site is cleaner than the rural Pry site
- Summer "first flush" ammonium concentrations higher



<u>Wider context:</u>

- Summer DO sags are at least as severe as the winter 2013-14 storms
- Winter DO in 2014-15 was roughly 2 mg/L higher than winter 2013-14
- **Impacts long lasting – but not severe?**

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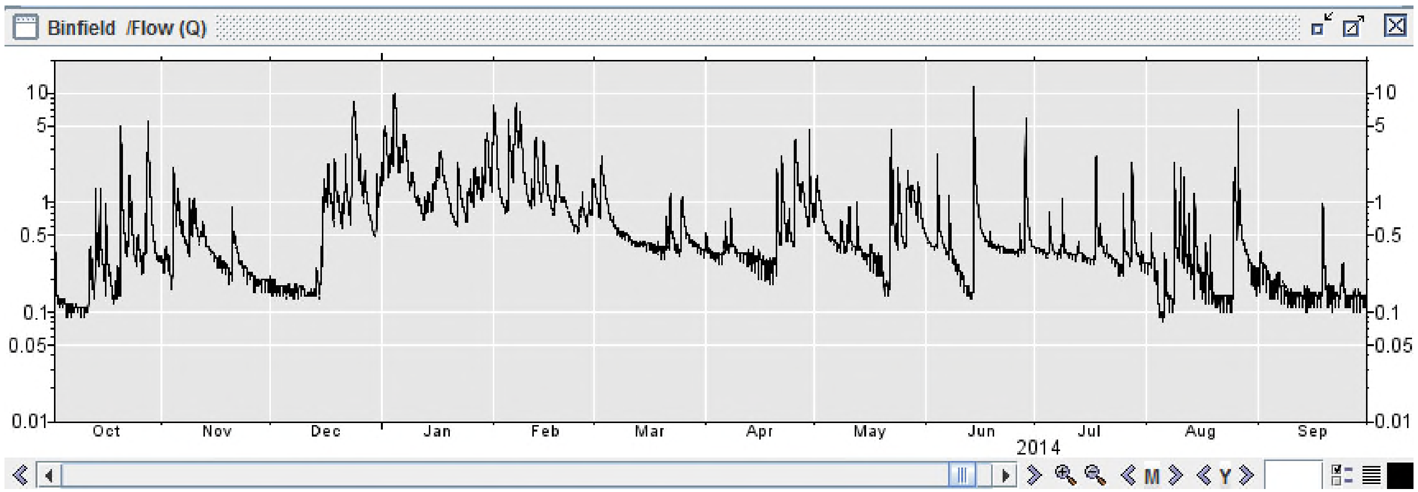
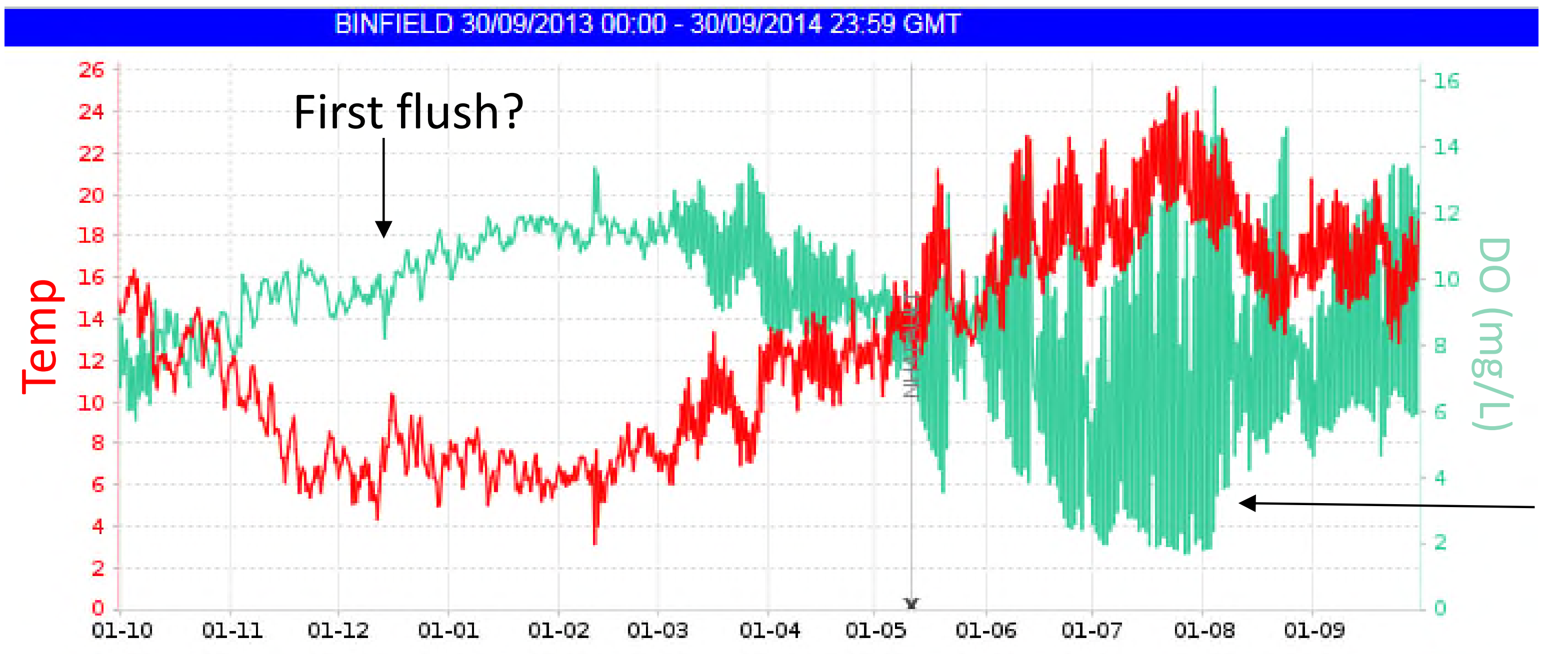
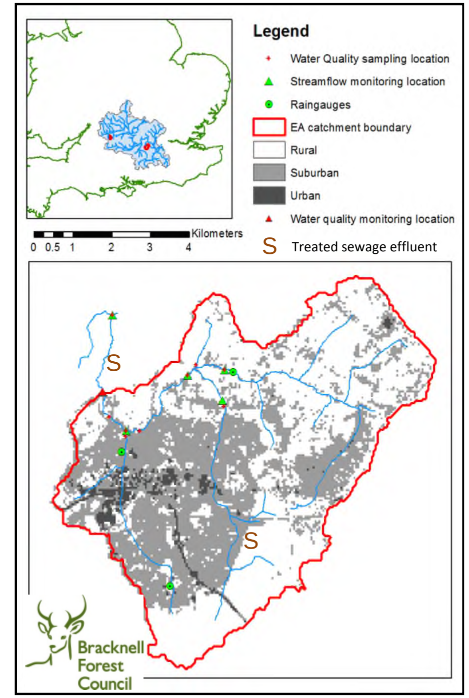
The Cut at Binfield: Sept 2013 - Oct 2014





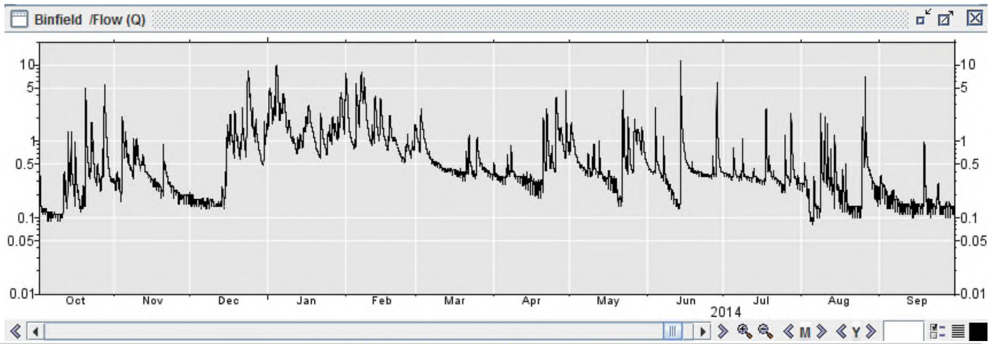


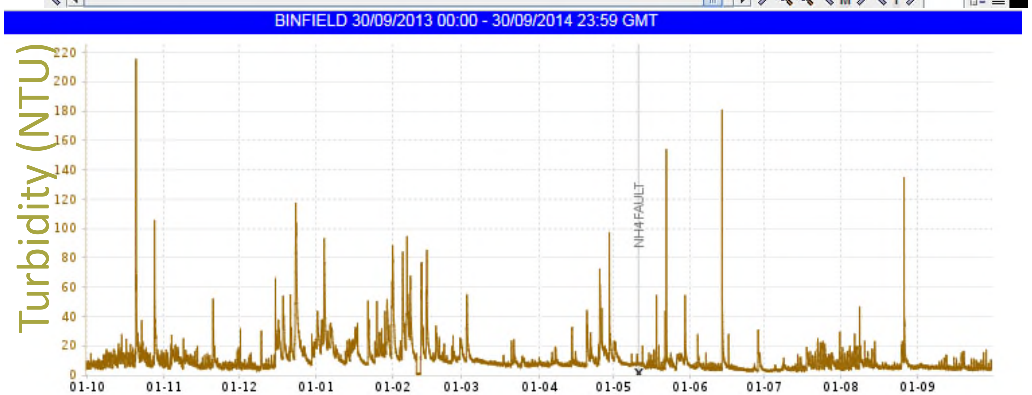
In terms of DO, winter storms have negligible impact compared to the benthic algal blooms throughout the summer

Winter 2013-14 storms

Identifying/modelling urban pollution from continuous record

From hourly flow and water quality time-series, we can identify conditions causing: 1) Overspills of untreated effluent, 2) First flushes of accumulated pollutants





Acute suspended solid (SS) flux

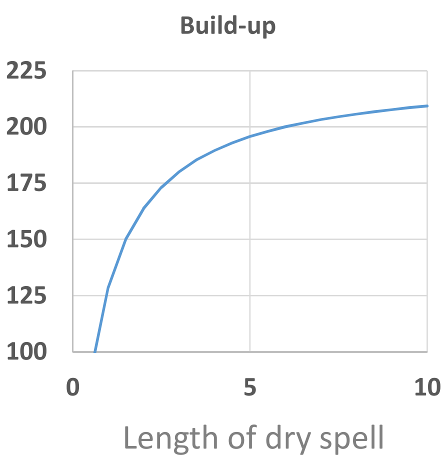
Binfield GS = 0.4 m^3/s

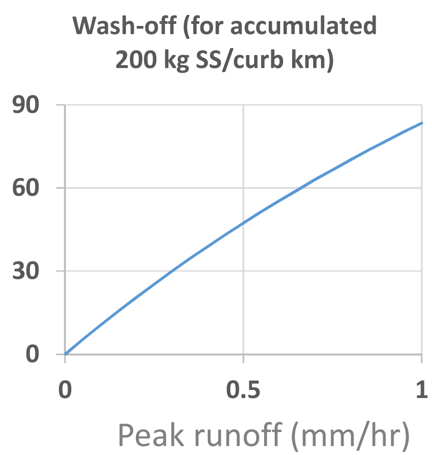
Dry spells below threshold (no SS peaks)

Observations of acute SS flux: derived from hourly paired flow/concentration (above SS threshold)

Binfield GS = 7 mg SS/L

Background flux below threshold





Model of first flush of sediment: based on urban morphology and daily flow data. Integrated to calculate annual load. **Assuming thresholds have not changed since 1970s, this reveals a 45-50% increase in acute SS flux per unit urban area**

Eutrophication in Thames: sensitivity analysis (QUESTOR)

Using a "present day" baseline, model applied many times (>3000) to cover full range of combinations of 5 stressors in the input data.

Stressors (represented in model inputs)	Sensitivity range: factors applied to daily time-series data S = scalar; Δ = change factor
River flow	S: 0.8 – 1.2
Phosphorus concentration (point, diffuse)	S: 0.2 - 3.0
Water temperature	Δ: -1^{o}C - +4^{o}C
Urbanisation (abstraction, effluent)	S: 0.8 – 1.5
Riparian shading	0% - 80%

Output assessed along river network in terms of summary indicators of eutrophication (e.g. 10th percentile DO (WFD), 90th percentile chlorophyll).

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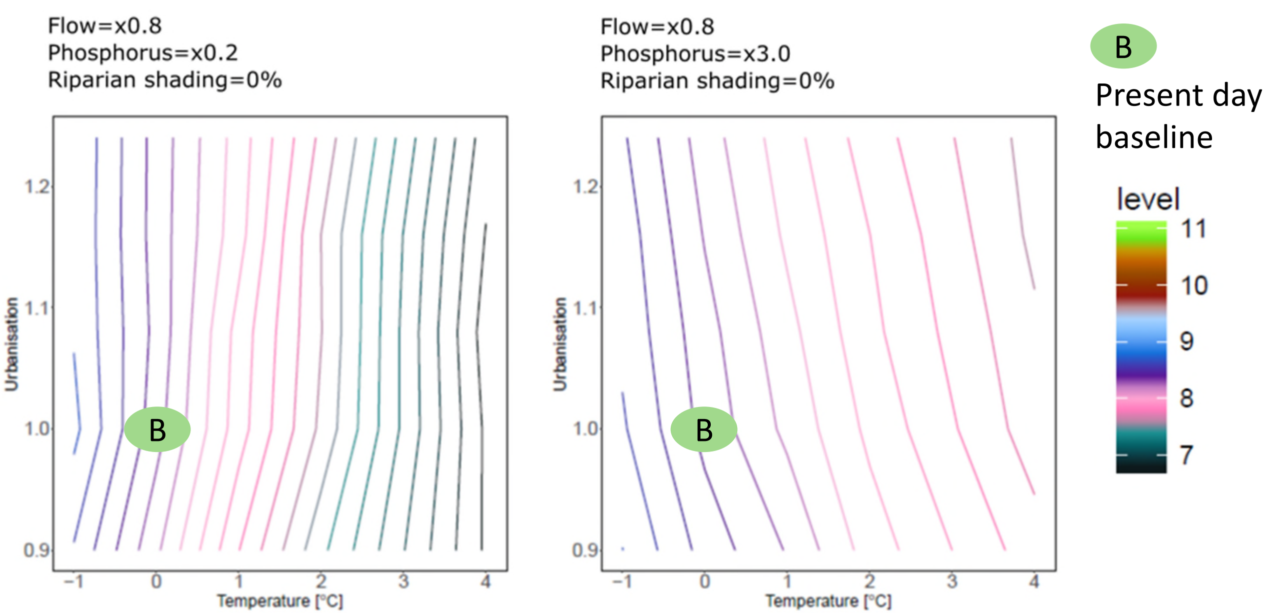
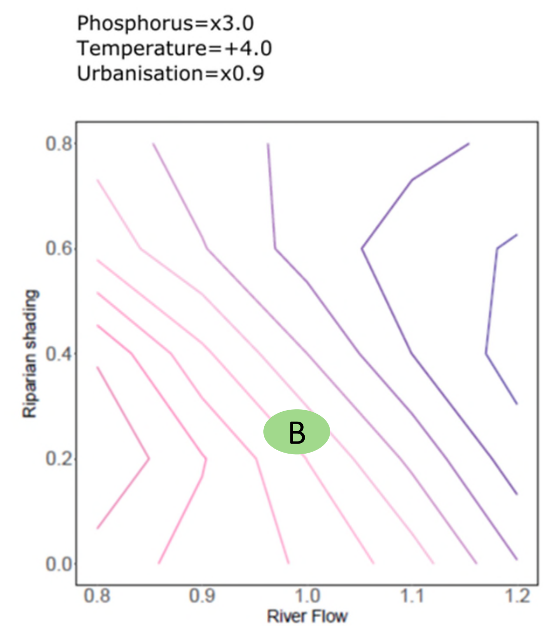
Output displayed graphically (contour plots)

- Climate stressors are usually dominant, but effects vary downstream and stressor interplay is very complex

e.g. 10th percentile mg DO/L (Thames at Wallingford): As phosphorus levels increase the combined effect on DO of temperature and urbanisation shifts from being neutral/mitigating to additive.



Complex interplay between flow and light stressors



But urbanisation effects at Wallingford are smaller than elsewhere as volumes of upstream abstraction and effluent largely balance out

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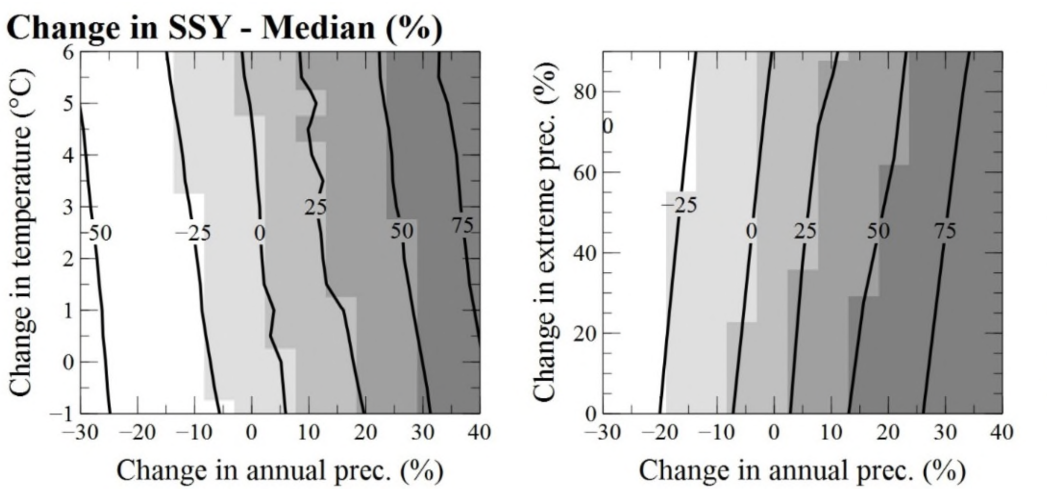
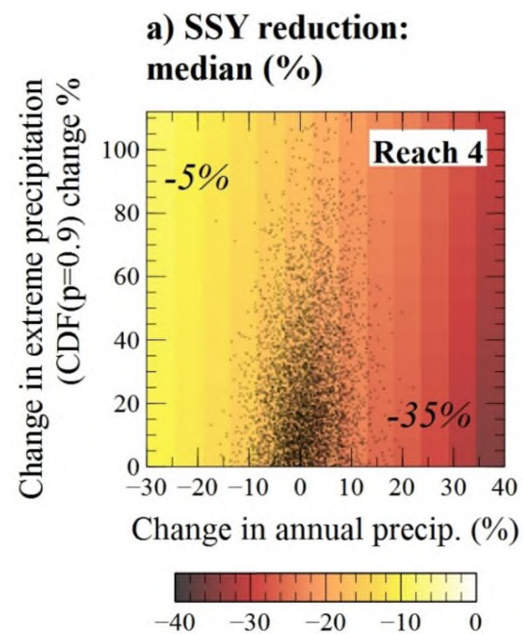
A scenario-neutral approach (INCA)

- Response of suspended sediment yield to change in climate (annual/extreme precipitation, annual temperature) and land-use (50% reduction arable land)
- Change in total precipitation has relatively large effects
- Climate and land-use interact to affect sediment response which varies along the river network





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Black dots represent UKCP09 projections

Conclusions

- Long-term data assessed using detection/attribution methodology:
  - Some upward trends in runoff in urban basins (but not in rural). URBEXT provides stronger signal of runoff change once effects of rainfall considered.
  - Water quality parameters show long-term improvements, due to upgrades in sewage treatment, approaching levels seen in rural catchments

- Urban pollution events may become more severe under urban growth and climate change. High uncertainty as to how the specific controls on first flush events will change. Can these largely be mitigated against by management and investment?

- At local scale urbanisation effects are important. Climate factors dominate downstream. Need to address suitability of climate projections for impact assessments at local urban scale.

Ongoing work

(i) combine sediment modelling approaches at local and catchment scale,

(ii) refine representation of urbanisation in QUESTOR scenario-neutral sensitivity analysis

Thank You

Collaborators…

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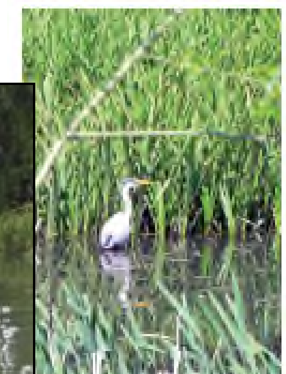
UNIVERSITY OF SURREY
UNIVERSITY OF OXFORD
Environment Agency
EARTHWATCH INSTITUTE



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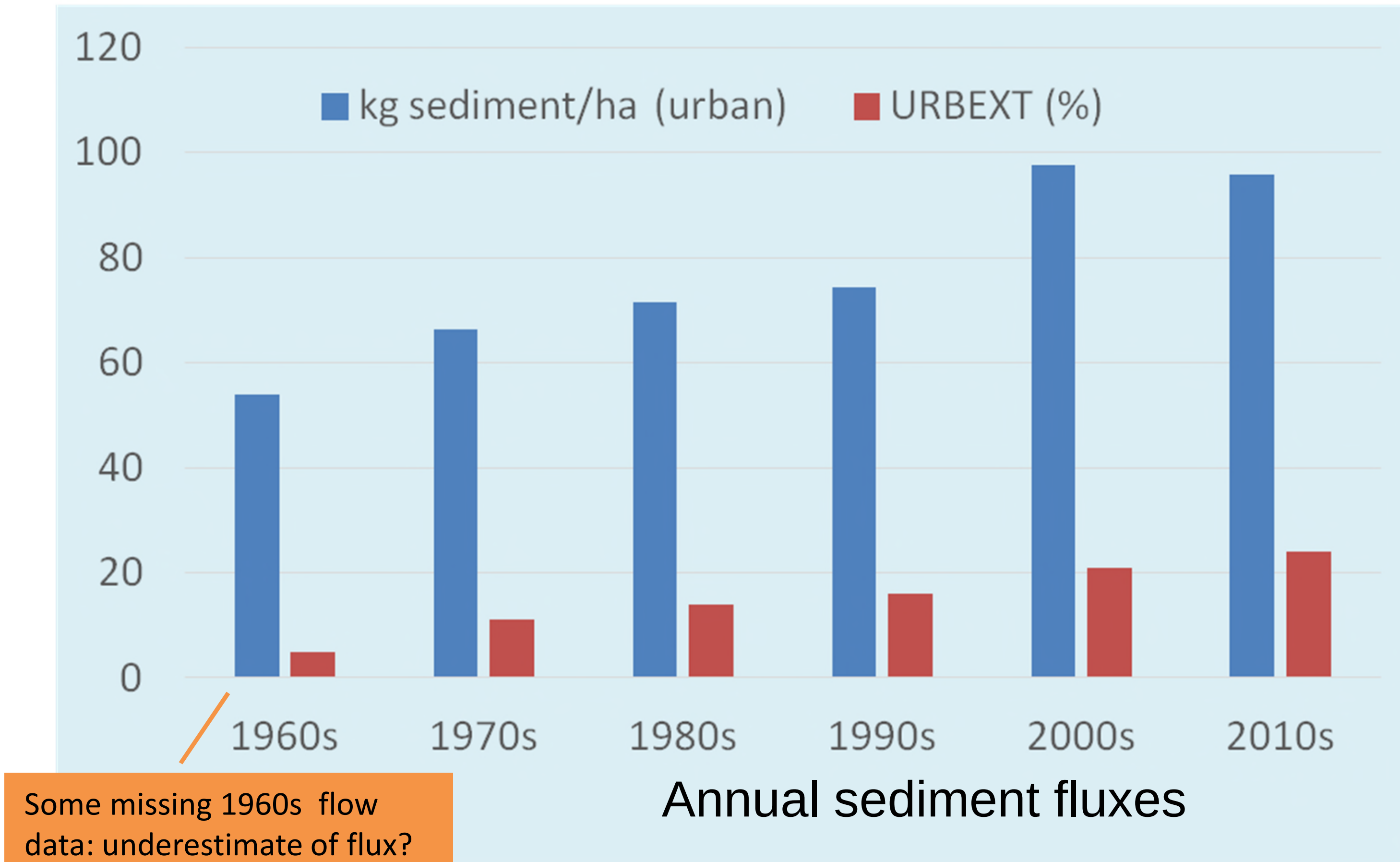
More information:
Recent blogs by Mike Hutchins, and link to journal publications:
http://www.ceh.ac.uk/news-and-media/blogs/urbanisation-has-impact-our-water-resources

Aggregated SS loads (kg/ha) from first flushes

1. Binfield	2013-14	2014-15
Simulated	35.47	20.81
Observed	39.95	22.74

Model testing:
1. Full year
2. Winter storm period

2. Rodbourne (6 km^2, URBEXT = 0.6)	13/12/2013-30/1/2014
Simulated	20.38
Observed	14.65



Results suggest SS fluxes per unit area of urban land appear to be increasing. Why?

- climatic factors
- changes in runoff regime due to urbanisation

Or, do differences in urban morphology between housing estates of different age cause older fluxes to be underestimated?